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The research on energy in spain: A scientometric approach

Francisco G. Montoya [a,*], Maria G. Montoya [b], Julio Gómez [b], Francisco Manzano-Agugliaro [a], Enrique Alameda-Hernández [c]

[a] CEIA3, Department of Engineering, Universidad de Almería, 04120 Almería, Spain
[b] Department of Informatics, Universidad de Almería, 04120 Almería, Spain
[c] Department of Civil Engineering, Universidad de Granada, 18071 Granada, Spain

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ABSTRACT

This work describes the features of the contributions made by the Spanish institutions to the specialized literature in the energy field in the period 1957–2012. The source considered has been the Scopus Elsevier database, together with bibliometric analysis techniques. All items provided by Scopus have been taken into account in the analysis (journal papers, conference proceedings, etc.). The results of this work show that the Spanish contribution is more that significant in the light of the obtained data, being the keywords power, energy, system, wind and solar the most used terms. Different aspects of the publications are analyzed, such as publication type, field, language, subcategory and journal type, as well as the keyword occurrence frequency. The contributions are geographically and institutionally broken down, with Madrid and Catalonia the main researching regions. At an international level, Spain mainly works jointly with France, USA, Germany and the United Kingdom. The most active categories in the Energy field are Engineering, Materials Science and Chemistry. It can be stated that the Spanish research enjoys good health and is an important and relevant player in the international scientific scene.

Contents

1. Introduction

Energy in all its facets is a very interesting field of study for the scientific community [1]. Both the generation and the distribution or its final use are the topic of numerous studies in diverse disciplines such as engineering, material sciences and chemistry [2–7]. In general, the economic and industrial development make use of energy resources [8,9] in order to cover the growing needs of world population. So, the energy related research trends analysis is of paramount importance, because it provides a detailed view about the advances and future work lines [10–12].

The Spanish specific case deserves special attention given to the innate scarceness of energy resources that the country suffers [13]. Traditionally, Spain has had very little gas and liquid hydrocarbons, or they have been of low quality [14]. The national coal is a similar example [15] with the additional problem that it is

* Corresponding author. Tel.: +34 950214501.
E-mail addresses: pagilm@ual.es (F.G. Montoya), mari@ace.ual.es (M.G. Montoya), jgomez@ual.es (J. Gómez), fmanzano@ual.es (F. Manzano-Agugliaro), ealameda@ugr.es (E. Alameda-Hernández).

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obtained at a higher cost than other third countries coals. Recently, renewable energies have turned up to slightly lessen this situation. Thanks to the latest Governments support, the wind and solar energy take off has been clear [16–23], generating great activity in the energy auxiliary sectors.

Lately, the study of the marine energy resources in Spain has pointed out that they can be of help to improve this situation, mainly in the Atlantic coast [24–26] and in the Canary Islands [27–29], as well as the seasonal biomass use [1,30–33]. Even though, Spain still is a relatively poor country regarding energy self-provision, this does not prevent its institutions and researchers publications and research from playing a relevant role in the international scene [34–38].

The state of the Spanish research analysis reveals a growing interest from its beginnings back in the 50s with the creation of the Junta de Energia Nuclear, JEN (Nuclear Energy Board) [39], mainly focused on atomic research. Later on, and thanks to the creation of different institutes and public centers, the diversification into other disciplines, such as wind or solar energy, started [40]. Nowadays, there are four great public research centers: Centro Superior de Investigaciones Científicas, CSIC (Scientific Research Higher Center), Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, CIEMAT (Energy, Environment and Technology Research Center), Instituto Nacional de Tecnología Aeroespacial, INTA (Aerospace Technology National Institute) and the Instituto Geológico y Minero, IGME (Geology and Mine Institute). Among these centers, only the first one is in the top twenty of world institutions with highest number of publications about biomass as energy resource [1]. Certainly, besides these great public units, a great amount of Spanish research is based on research groups belonging to different universities of the country, up to 71 universities [41].

Then, knowing the distribution of the Spanish scientific scene regarding the energy research is of special interest. The main objective of this work lies in analyzing the research state and trends in the energy field during the last 50 years in Spain in order to help the research community understand the current situation and future trends, as well as predict the dynamic changes that could appear in the work lines.

The Scopus database has been chosen in this work as information source for the analyzed data, given that it counts with a more than 49 millions records catalog from nearly 20,500 titles and 5000 publishing houses. Scopus is accepted by the international scientific community as one of the two biggest data sources for the analysis of scientific publications [42].

2. Materials and methods

A complete search in the Scopus database has been carried out using sub-fields *subjarea* and *affilcountry* to find publications about the energy topic in which any Spanish researcher or research center has taken part. The search range goes from 1957 to 2012 (included). The different energy research sub-fields comprise all the spectrum related to any type of energy use.

The retrieved records have been treated using spread sheets and a specific open source tool, OpenRefine (http://openrefine.org/). This app is a standalone desktop application initially developed by Google for data cleanup and transformation to other formats. In this way, the messy, conflicting or disorganized text analysis is greatly eased, obtaining very satisfactory results that could be nearly impossible to get due to the extent of the working database otherwise. Each record obtained from Scopus follows Table 1 structure. The personalized export option, that the database provides, has been used.

As can be seen, more than enough information is available so rates and statistics about many field of interest can be computed.

3. Results and discussion

3.1. Type of publications and languages of publications

Fig. 1 shows the distribution of the 12,532 Spanish energy contributions in the period 1957–2012. Mainly, consisting of journal papers (8858/70.66%) and conference papers (3241/25.85%). Reviews (322/2.57%) and editorials (42/0.34%) have a less important weight.

Table 1
Structure of each record exported from the Scopus database.

Field	Value
Authors	Serrano Gonzalez J., Burgos Payan M., Riquelme Santos J.
Title	Optimum design of transmissions systems for offshore wind farms including decision making under risk
Year	2013
Source title	Renewable Energy
Volume	59
Issue	
Art. no.	
Page start	115
Page end	127
Page count	
Cited by	
Link	http://www.scopus.com/inward/record.url?eid=2-s2.0-84876721373&partnerID=40&md5=7c537f3664b7e0d1732b0d6f19fc2dc2
Affiliations	Department of Electrical Engineering, University of Seville, Seville, Spain
Authors with affiliations	Serrano Gonzalez, J., Department of Electrical Engineering, University of Seville, Seville, Spain Burgos Payan, M., Department of Electrical Engineering, University of Seville, Seville, Spain Riquelme Santos, J., Department of Electrical Engineering, University of Seville, Seville, Spain
Author keywords	Cost-benefits optimization; Decision making under risk; HV transmission system; HVDC-VSC; Offshore wind farms
Index keywords	
References	Complete list of references
ISSN	9601481
ISBN	
CODEN	
DOI	10.1016/j.renene.2013.03.024
Document type	Article
Source	Scopus

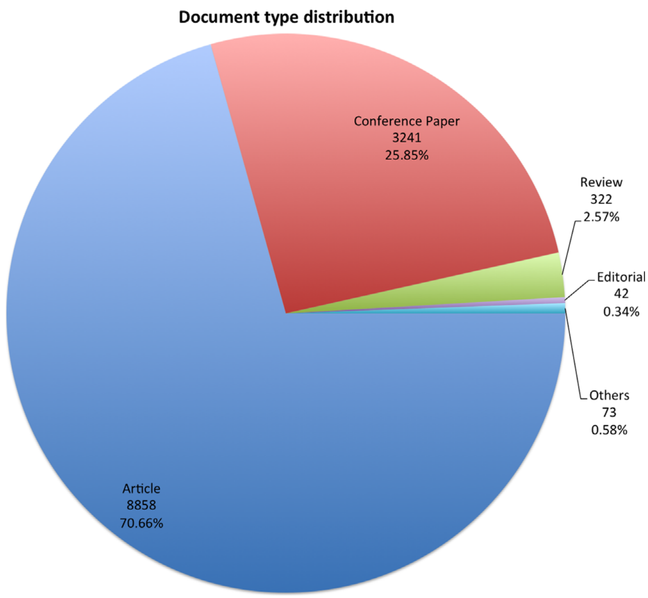

Fig. 1. Chart representation of document type distribution during period 1957–2012 for Spanish energy research.

Due to the fact that most of the work are journal papers, English has been the most used language, reaching 12,202 documents (97.33%), followed by Spanish 317 documents, and anecdotally German (9), Chinese (4) and French (4).

3.2. Characteristics of scientific output

Fig. 2(a) shows the time evolution of the analyzed papers, that is, energy related publications between 1957 and 2012 where Spanish institutions appear. It can be seen that from 2005 the growth is particularly noteworthy. Fig. 2(b) represents the same information but now in a logarithmic scale, giving an idea of the growth rate. It is verified that the trend is exponential from the beginning of the 80s up to now, without any loss in the growth rate. In the same Fig. 2(b), the linear correlation model has been included, with a coefficient $R^2 = 0.965$.

3.3. Publication distribution by regions and institutions

Regional development of technology in Spain has been very uneven from its start, with existing zones of great development (mainly Madrid, Catalonia and the Basque Country) and others very little developed (like Andalusia or Extremadura).

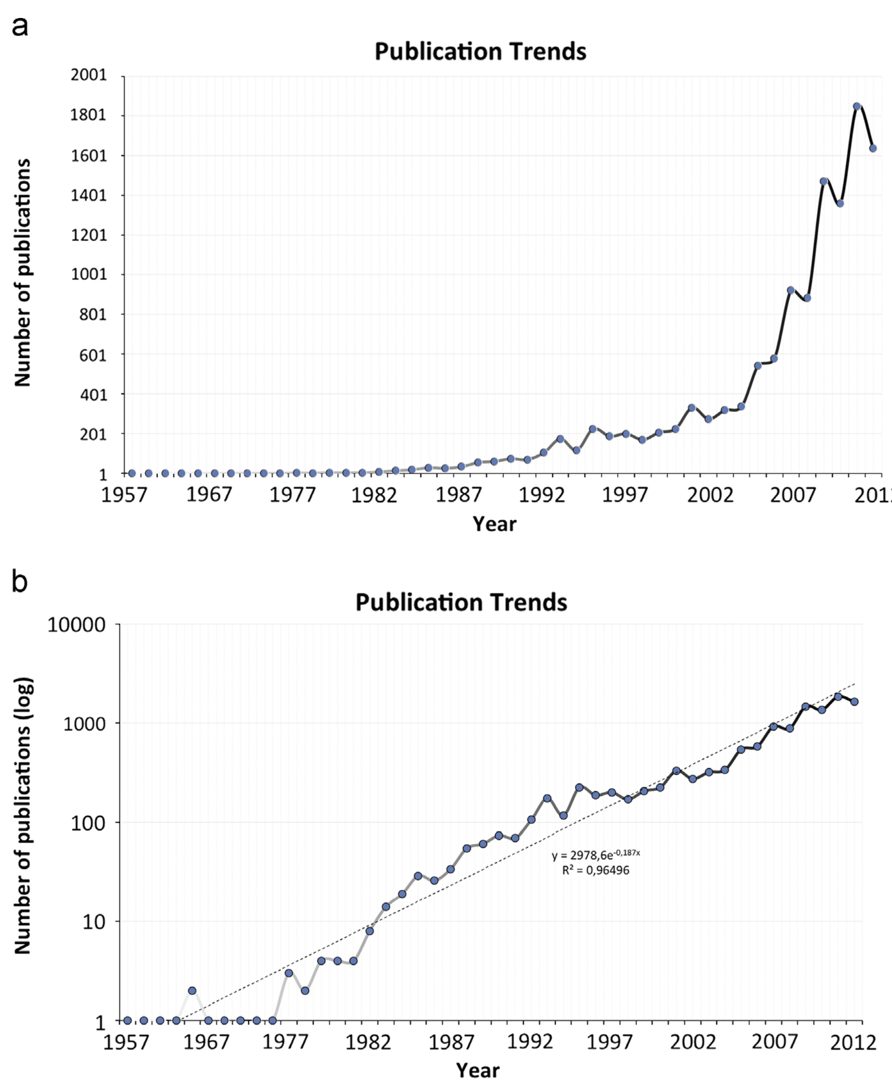

Fig. 2. Publications evolution in the period 1957–2012 for Spanish institutions. Linear (a) and logarithmic scale in y-axis (b).

This unevenness is becoming less important as time evolves and above all due to the great industrial and technological development in Spain during the end of the 20th century and the beginning of the 21st century. Fig. 3 shows a map with the distribution of the energy publications by Comunidades Autonomas (the Spanish 17 administrative regions). From this figure it can be deduced that the more active institutions are those belonging to Madrid (3956), Catalonia (1841) and Andalusia (1460), while those less active belong to Extremadura (154), Murcia (152), Navarra (141), Cantabria (128), Baleares (48) and La Rioja (47). Madrid and Catalonia are clear examples of the economic and industrial development of both regions, unlike Andalusia that has traditionally been a poor region enjoying far less resources, but that has 10 public universities compared to a single one in Extremadura or in Castilla la Mancha.

The most prolific institutions have been classified in Fig. 4. Standing out in first place two public centers with a clear R&D nature, the CSIC (1686/13.45%) and the CIEMAT (1058/7.53%). Both the CSIC and the CIEMAT have a number of centers scattered on the whole national geography. Closely behind, the three most important engineering universities follow, which are the Polytechnic University of Madrid (944/7.43%), the Polytechnic University of Catalonia (706/5.63%) and the Polytechnic University of Valencia (595/4.75%). Again, it can be noted how the Comunidad de Madrid and Catalonia play a dominant role in the Spanish energy research scene, but undoubtlessly it is due to the position that they hold within the Spanish (Sp) and world (W) universities ranking: Polytechnic University of Catalonia (Sp=2, W=132), Polytechnic University of Madrid (Sp=3, W=135), Polytechnic University of Valencia (Sp=8, W=245).

Fig. 5 shows the time evolution of the 9 most prolific institutions during the last 10 years, 2003–2012. In general, there exists an upward trend in the number of publications per institution, although drops occur as well during certain years. For example, the CSIC falls from 2007 to 2008, like the CIEMAT in 2009–2010 or in 2011–2012. This type of behavior is often influenced by the start/end dates of the grant programs application periods in which the public institutions participate.

Data regarding international collaboration of the Spanish institutions researchers show that this collaboration has been abundant, collaborating with a grant total of 104 countries. Table 2 shows, per country, the number of publications in which any Spanish institution has collaborated with any institution of that country. It can be confirmed that there are 18 countries counting more than 100 joint publications.

Fig. 6 represents Table 2 information, geolocalized and color-coded, for a better reading. There are four countries with which the collaboration is very high, over 600 publications: France (827), United States (752), Germany (748) and United Kingdom (747); one with high collaboration, over 400: Italy (562) and four countries with medium-high collaboration, over 200: Portugal (300), Netherlands (280), Belgium (246) and Switzerland (237). Of all these 9 countries, 7 belong to the European Union, that is, the Spain closest neighboring countries. On the contrary, it is remarkable the little collaboration with North Africa in general and Morocco (24) in particular, being the late a Spain bordering country and suffering from great energy lacks. More than 85% of Moroccan energy in use is imported [43]. Furthermore, it has relevant energy potential resources, both solar resources, i.e. it intends to convert solar energy in areas with high solar irradiation into electrical energy by means of Concentrated Solar Power (CSP) transferring this energy by High Voltage Direct Current (HVDC) lines into the whole European Union, Middle East and North Africa (EU-MENA) area [44], and wind resources [45].

Finally, it must be highlighted that a good part of this collaboration is merely testimonial, with 44 countries counting just 1–2 collaborations, and 19 with just 3–7. Among countries with medium collaboration, and far away geographically, it is noteworthy the collaboration with Canada, Brazil, Mexico or Sweden.

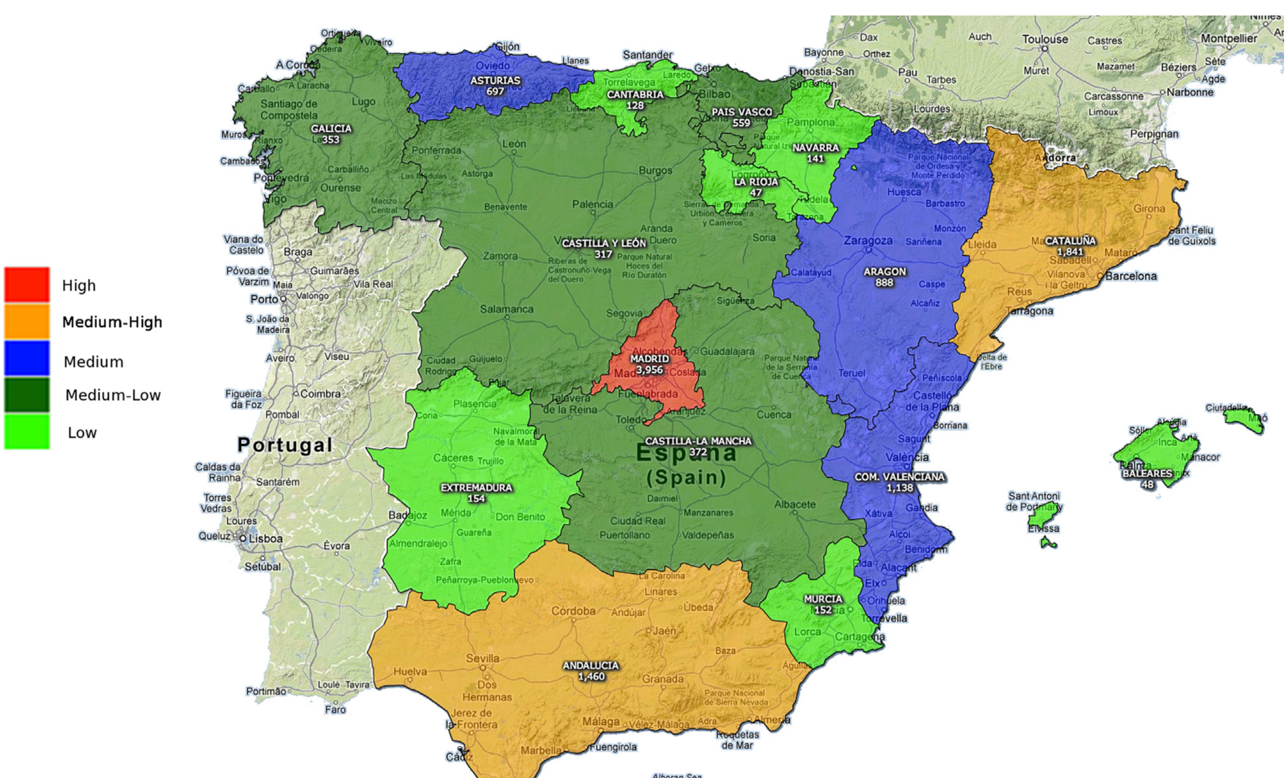

Fig. 3. Publication distribution by Spanish regions. Red is for a high publication level, while green is a low one. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

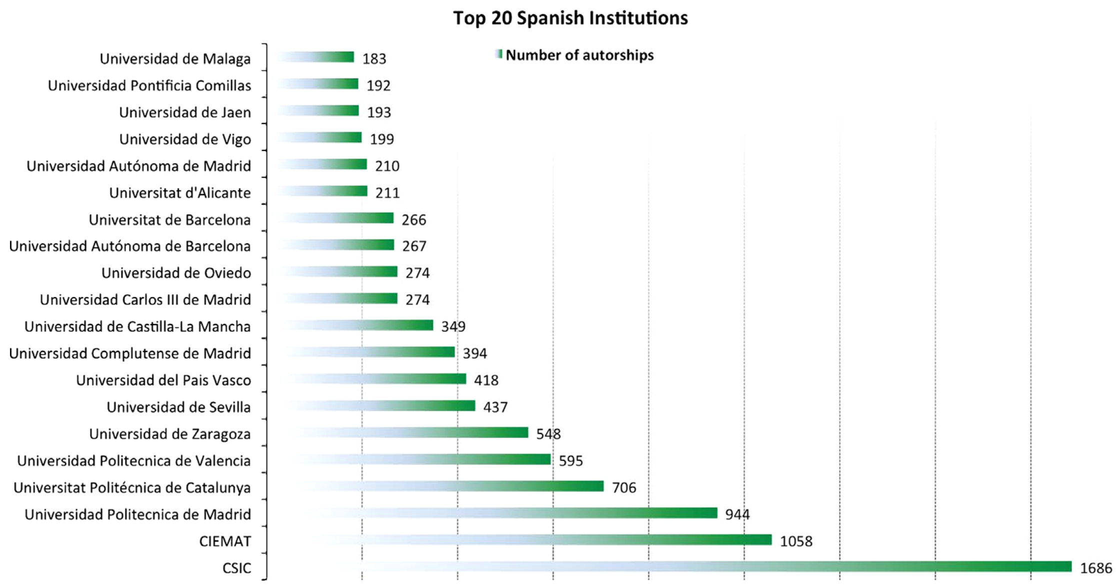

Fig. 4. Ranking including the 20 most prolific Spanish institutions on energy research (1957–2012).

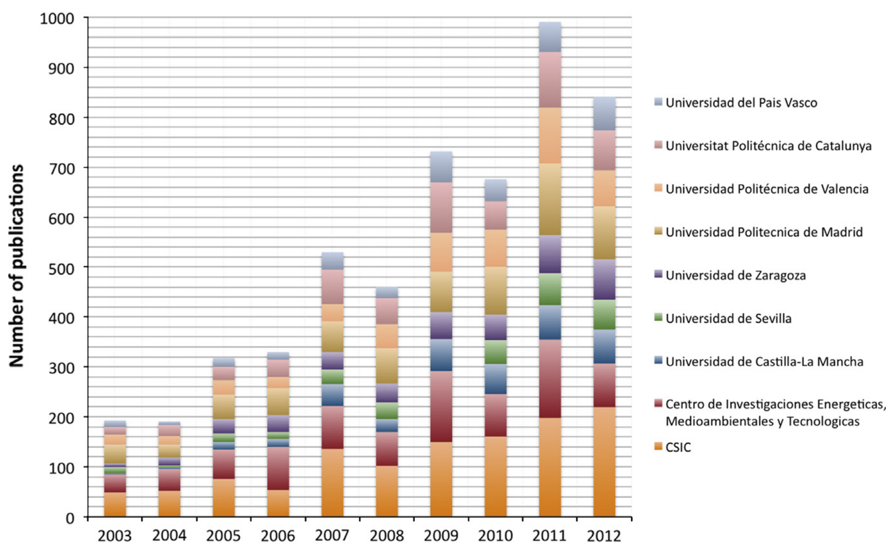

Fig. 5. Time evolution for the 2003–2012 period of the 9 most prolific institutions.

3.4. Distribution of output in subject categories and journals

Fig. 7 shows the classification according to subjects that co-exist with the energy subject. There is a predominant group such as Engineering (4119/33.09%), Materials Science (3007/23.98%), Chemistry (2889/23.04%), Physics and Astronomy (1801/14.36%), Chemical Engineering (1712/13.65%) and Environmental Science (1365/10.89%), being the rest far more minority.

Table 3 lists the top 30 journals where Spanish institutions publish in greater number their research results, covering 58% of Spanish contributions. Where *Journal of Physical Chemistry C*, *Fuel*, *Fusion Engineering and Design*, *Journal of Power Sources* and, *Energy and Fuels* top the list.

It can be noted that these journals belong to publishing houses of only three countries: United States, United Kingdom and Netherlands, except only one that is Spanish. Fig. 8 includes a comparative ranking according to the number of published papers, position held according to the Journal Citation Report (JCR) by Thomson-Reuters and position held according to the Scimago Journal Rank (SJR) by Elsevier. Each dot area is proportional to the position held in each index, so that the wider the area the upper in the ranking. Also, the last row, item, refers to the number of Spanish publication in this field published in that journal, ordered from bigger to smaller. It can be noted, for instance, that the first two journals, *Journal of Physical Chemistry C* and *Fuel*, are very well positioned in the index and also have a good number of contributions, but nevertheless, the journal *Fusion Engineering and Design*, that is not well positioned in the index concentrates a good portion of the Spanish research effort, given that it holds the third position according to publications number, furthermore this very same fact repeats with the *Ingeniería Química Spain* journal lacking of JCR impact factor. In the opposite situation, the *IEEE Transactions on Power Systems* and *Progress in Photovoltaics*: *Research and Applications* journals are really well positioned but the Spanish research has little presence in them.

Finally, Table 4 and Fig. 9 show data regarding the journal publications evolution in recent years, precisely during 1996–2011, in them a positive trend in the number of published papers is noticed, as well as a stagnation in the number of international collaborators in the 35–40% gap per year, what seems an adequate internationalization degree. In what respect to the 2010–2011

Table 2
Countries working jointly with Spanish institutions on the energy field during period 1957–2012.

Country	Items
France	827
United States	752
Germany	748
United Kingdom	747
Italy	562
Portugal	300
Netherlands	280
Belgium	246
Switzerland	237
Mexico	211
Sweden	191
Brazil	164
Denmark	160
Japan	152
Canada	150
Russian Federation	127
Finland	125
Argentina	107
Greece	96
Austria	94
Colombia	93
Poland	90
China	89
Venezuela	70
Norway	68
Australia	66
Czech Republic	66
Chile	62
Bulgaria	53
India	49
Ireland	48
Romania	44
Cuba	43
Hungary	43
Israel	35
Ukraine	34
Turkey	31
South Korea	31
Algeria	27
Slovenia	25
Morocco	24
Slovakia	21
Egypt	19
Uruguay	17
Iran	17
Belarus	16
Croatia	14
Peru	14
Malaysia	14
South Africa	12
Saudi Arabia	10
Cyprus	10
New Zealand	10
Tunisia	7
Taiwan	6
Monaco	6
Lithuania	5
Luxembourg	5
Hong Kong	5
Indonesia	5
Uzbekistan	5
Latvia	4
Lebanon	4
Qatar	4
Senegal	4
Singapore	4
Estonia	4
El Salvador	4
Malta	3
Thailand	3
Trinidad and Tobago	3
Moldova	3
Lesotho	3
Pakistan	2
Paraguay	2
Nicaragua	2
Serbia	2
Honduras	2
Armenia	2
Costa Rica	2
Macedonia	2
Bosnia and Herzegovina	1
Kuwait	1
Kenya	1
Nigeria	1
Iraq	1
Netherlands Antilles	1
Mongolia	1
Andorra	1
Puerto Rico	1
Guatemala	1
Laos	1
Bahrain	1
Angola	1
French Polynesia	1
Philippines	1
United Arab Emirates	1
Kazakhstan	1
Ecuador	1
Libyan Arab Jamahiriya	1
Jordan	1
Dominican Republic	1
VietNam	1
Zambia	1

publications number, these nearly double in number. Regarding the citation number, 2006 peaked at a little more than 5300. Noteworthy is the number of self-citations, always higher than the published papers, although this self-citations number per published paper shows, in general, a decreasing trend, from 4.59 in the year 1996 to 0.48 in the year 2011.

3.5. Analysis of author keywords

Keyword analysis in research papers is very interesting in order to follow and search the trends in the science and engineering branches [46,47]. As a result of our work, a total of 16,055 different keywords, from 1957 to 2012 in the energy field, has been identified. To obtain this quantity a refine process, of the Scopus provided data, has been necessary, given that initially, the number was greater. In particular, the number of analyzed publications during the studied period was 12,536. Of them, only 7409 provide keywords, while the rest (5127) do not provide the mentioned information. The counting of the raw total of keywords produces the quantity of 33,189, of which 18,617 are different, although actually the existence of several versions of how each author writes the keywords has been detected. For instance, “ENERGY” can be found like “Energy”, “energy”, “Energies” or “energi”, giving rise to different versions of the same concept. To solve this problem the open source tool OpenRefine has been employed. This tool allows to make clustering and merging of text showing a certain degree of similarity using specifically designed algorithms [48]. After applying the refinement algorithm the final figure of 16,055 unique keywords is obtained. Among these unique keywords, 13,705 (85.36%) appear once or twice at the most, what can be a sign of lack of research continuity or of a wide range of research focus [49]. Table 5 shows the 50 most relevant keywords during the considered period.

From Table 5 it can be deduced that “Power Quality”, “Hydrogen” and “Modeling” are the three terms most used by researchers. It is interesting to note how keywords consist mainly of two or

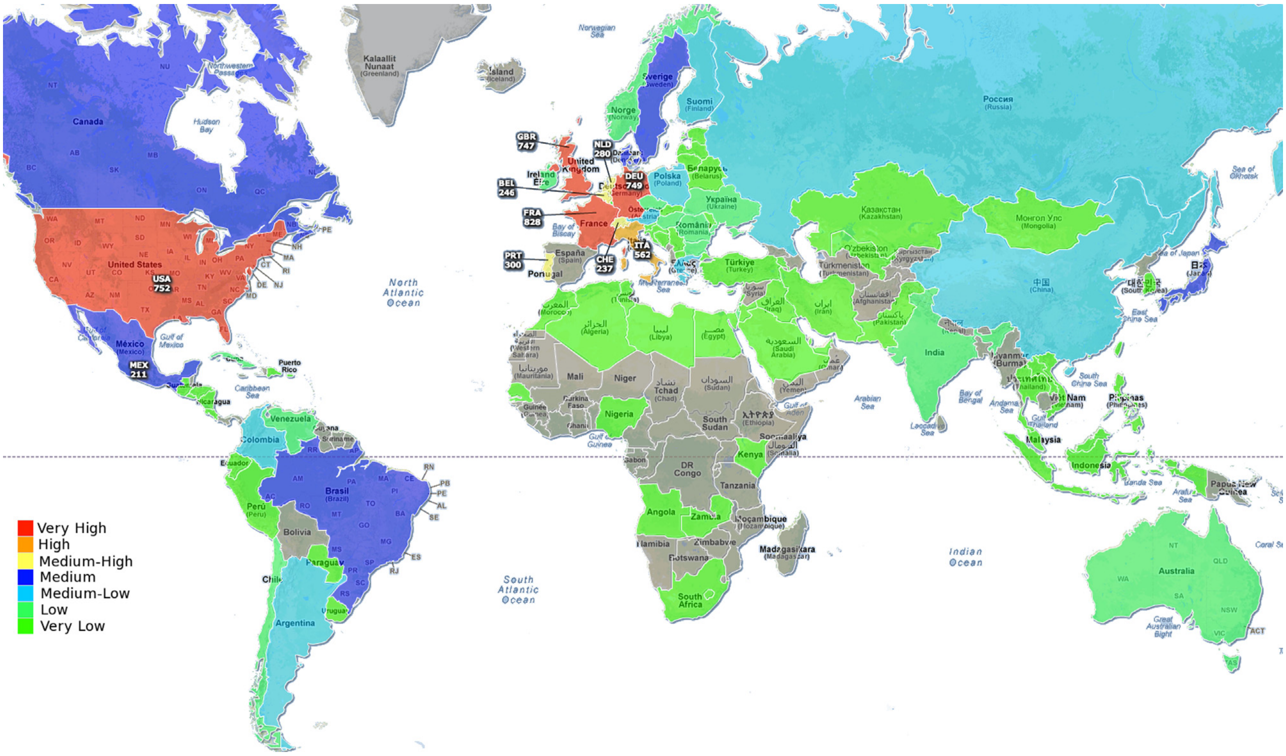

Fig. 6. Collaboration intensity of countries working jointly with Spanish institutions in the considered publications.

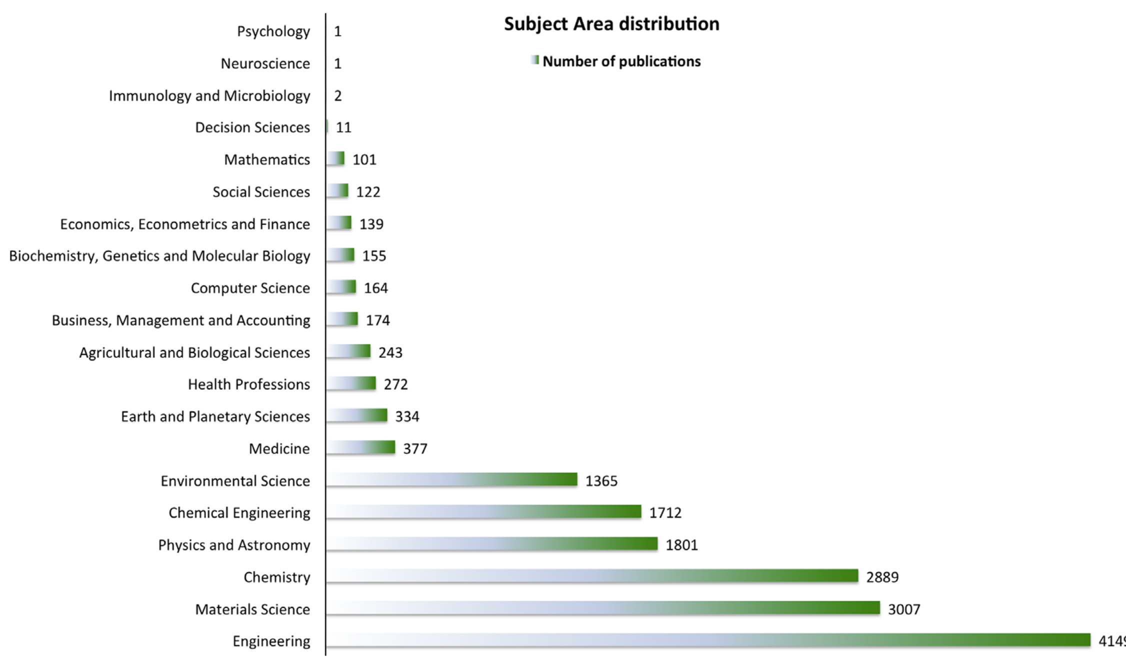

Fig. 7. Publications distribution according to the subject classified by Scopus.

three words, what gives rise to a wider dispersion in the occurrence frequency of certain terms like "energy", "power" or "generation", to mention just a few. To obtain a more complete picture, a refinement over the compound keywords has been carried out, braking them down in their base words. In this case, 65,042 derived words have been obtained from the 16,055 initial keywords. Table 6 shows the result of this refinement process. Now the presence in top positions of terms like Power, Energy, System, Wind or Solar can be confirmed, clearly ahead of the rest. The fact that the term Spain is among the analyzed energy keywords attracts the attention, this leads to think that for the Spanish researchers the geographical location of their work is very important, given that the term is in 19th position.

Fig. 10 shows a graph of these 5 terms trend during the analyzed period. A clear upward trend at the beginning of 2000 can be observed and also how this evolution continues up to date, revealing that the studied keywords still appeal to the research community.

Table 3
Top 30 international journals where the Spanish institutions research is published in greater number.

Journal	Items	%	JCR	SJR	Country	Item ranking	JCR ranking	SJR ranking
Journal of Physical Chemistry C	803	6.41	4.805	1.947	United States	1	5	5
Fuel	578	4.61	3.248	1.796	Netherlands	2	10	8
Fusion Engineering and Design	421	3.36	1.49	0.584	Netherlands	3	24	26
Journal of Power Sources	402	3.21	4.951	1.882	Netherlands	4	4	6
Energy and Fuels	388	3.10	2.721	1.377	United States	5	15	13
International Journal of Hydrogen Energy	341	2.72	4.054	1.22	United Kingdom	6	7	19
Solid State Ionics	320	2.55	2.646	1.173	Netherlands	7	17	21
Solar Energy	285	2.27	2.475	1.272	United Kingdom	8	18	18
Fuel Processing Technology	276	2.20	2.945	1.349	Netherlands	9	12	14
Renewable Energy	263	2.10	2.978	1.564	Netherlands	10	11	9
Ingenieria Quimica Spain	242	1.93	0	0	Spain	11	30	30
Radiation Protection Dosimetry	235	1.87	0.822	0.489	United Kingdom	12	28	28
Energy Policy	224	1.79	2.723	1.386	Netherlands	13	14	12
IEEE Transactions on Nuclear Science	224	1.79	1.447	0.553	United States	14	26	27
Energy	218	1.74	3.487	1.432	United Kingdom	15	9	11
Solar Energy Materials and Solar Cells	213	1.70	4.542	1.844	Netherlands	16	6	7
Applied Thermal Engineering	208	1.66	2.064	1.273	United Kingdom	17	21	17
Energy Conversion and Management	158	1.26	2.216	1.208	United Kingdom	18	19	20
Renewable and Sustainable Energy Reviews	157	1.25	6.018	2.447	United Kingdom	19	1	2
Electric Power Systems Research	150	1.20	1.478	1.279	Netherlands	20	25	15
Journal of Nuclear Materials	142	1.13	2.052	0.81	Netherlands	21	22	23
Applied Energy	139	1.11	5.106	2.277	Netherlands	22	3	4
Biomass and Bioenergy	136	1.08	3.646	1.525	United Kingdom	23	8	10
Journal of Chemical Technology and Biotechnology	126	1.01	2.168	0.861	United Kingdom	24	20	22
Journal of Cleaner Production	121	0.97	2.727	1.273	United Kingdom	25	13	16
Progress in Photovoltaics: Research and Applications	119	0.95	5.789	2.678	United Kingdom	26	2	1
Nuclear Engineering and Design	111	0.89	0.765	0.645	Netherlands	27	29	24
Journal of Radioanalytical and Nuclear Chemistry	110	0.88	1.52	0.477	Netherlands	28	23	29
Fusion Science and Technology	95	0.76	1.12	0.587	United States	29	27	25
IEEE Transactions on Power Systems	92	0.73	2.678	2.41	United States	30	16	3

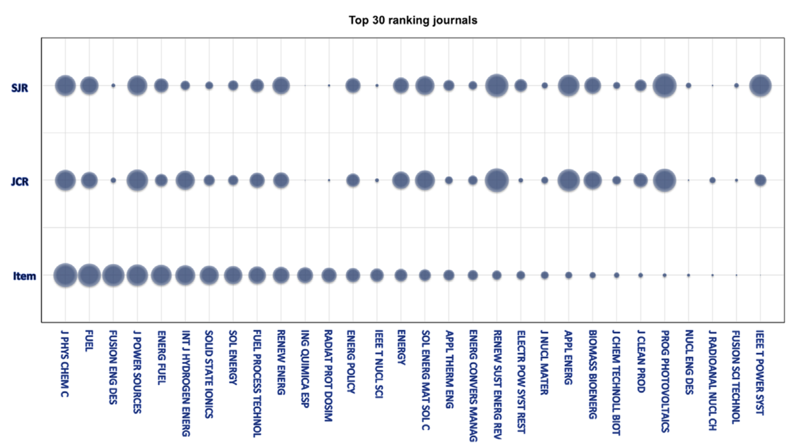

Fig. 8. Top 30 journals ranking according to different criteria. Item is the number of papers published in the journal, JCR it the Journal Citation Report by Thomson-Reuters, and SJR is the Scimago Journal Rank by Elsevier. The bigger the dot, the bigger the importance within the ranking.

Table 4
Trend in the energy papers publication by Spanish institutions in indexed journals during the 1996–2011 period.

Year	Documents	% Int. colab.	Citable doc	Cites	Self-cites	Cites per doc	Self-cites per doc	Cited docs	Uncited docs
1996	120	31.67	120	1756	551	14.63	4.59	109	11
1997	123	31.71	123	1522	396	12.37	3.22	103	20
1998	128	27.34	127	1693	551	13.23	4.3	112	16
1999	155	29.68	155	2355	618	15.19	3.99	142	13
2000	160	30.63	158	2530	628	15.81	3.93	146	14
2001	200	44	196	1920	575	9.6	2.88	160	40
2002	228	38.16	227	3458	860	15.17	3.77	206	22
2003	225	42.22	225	3898	740	17.32	3.29	204	21
2004	265	46.04	258	3738	986	14.11	3.72	228	37
2005	376	37.23	372	4814	1,144	12.8	3.04	325	51
2006	377	41.11	372	5318	1,041	14.11	2.76	329	48
2007	456	36.4	451	4892	1,327	10.73	2.91	405	51
2008	441	37.41	438	4410	1,108	10	2.51	394	47
2009	694	39.19	691	5077	1,391	7.32	2	590	104
2010	660	35.76	654	2734	892	4.14	1.35	521	139
2011	1048	42.84	1036	1446	501	1.38	0.48	537	511

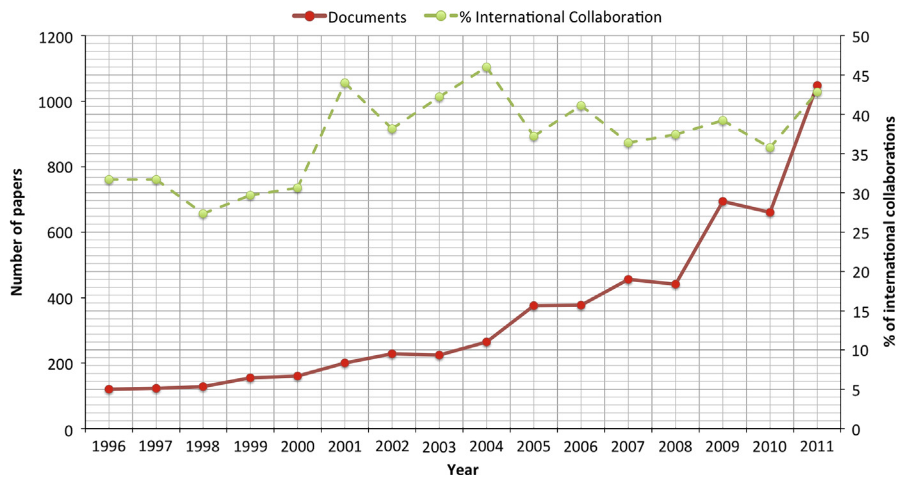

Fig. 9. Spanish international collaborations in the energy topic. Absolute value (red) and percentage over total (green). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

Table 5
List of the 50 most used keywords.

Keywords	Items	%	Ranking
Power quality	146	0.440	1
Hydrogen	137	0.413	2
Modelling	134	0.404	3
Biomass	129	0.389	4
Coal	126	0.380	5
Renewable energy	107	0.322	6
Fuel cell	106	0.319	7
ITER	106	0.319	8
Wind Energy	103	0.310	9
Optimization	99	0.298	10
Simulation	92	0.277	11
Biodiesel	88	0.265	12
Hydrogen production	84	0.253	13
Distributed generation	79	0.238	14
Adsorption	76	0.229	15
Wind power generation	71	0.214	16
Combustion	67	0.202	17
Electricity markets	64	0.193	18
Spain	61	0.184	19
CO_2 capture	60	0.181	20
Solar energy	60	0.181	21
Life cycle assessment	59	0.178	22
Gasification	58	0.175	23
PEMFC	58	0.175	24
Activated carbon	56	0.169	25
SOFC	55	0.166	26
Pyrolysis	54	0.163	27
Photovoltaic	53	0.160	28
Wind power	51	0.154	29
Energy efficiency	48	0.145	30
Energy	46	0.139	31
Neural networks	45	0.136	32
Diesel engines	44	0.133	33
Reliability	44	0.133	34
Emissions	42	0.127	35
Genetic algorithms	42	0.127	36
Trace elements	42	0.127	37
Wind turbine	42	0.127	38
Efficiency	41	0.124	39
Fly ash	41	0.124	40
Kinetics	41	0.124	41
Solar cells	41	0.124	42
Ethanol	40	0.121	43
Data acquisition	39	0.118	44
Heat transfer	39	0.118	45
CFD	38	0.115	46
Thermal energy storage	38	0.115	47
Cathode	37	0.111	48
Biofuels	36	0.108	49
Perovskite	36	0.108	50

Table 6
List of used words in the authors keywords.

Refined keywords	Items	%	Ranking
Power	1327	4.00	1
Energy	1056	3.18	2
System	878	2.65	3
Wind	574	1.73	4
Solar	562	1.69	5
Analysis	498	1.50	6
Control	458	1.38	7
Cell	410	1.23	8
Hydrogen	371	1.12	9
Coal	345	1.04	10
Generation	336	1.01	11
Fuel	329	0.99	12
Modelling	321	0.97	13
Thermal	298	0.90	14
Model	283	0.85	15
Heat	273	0.82	16
Simulation	267	0.80	17
Carbon	266	0.80	18
Combustion	255	0.77	19
Voltage	243	0.73	20
Renewable	232	0.70	21
Electricity	231	0.70	22
Quality	230	0.69	23
Biomass	221	0.67	24
Distribution	216	0.65	25
Storage	215	0.65	26
Network	208	0.63	27
Emission	207	0.62	28
Cycle	204	0.61	29
Gas	202	0.61	30
Converter	200	0.60	31
Environmental	200	0.60	32
Optimization	199	0.60	33
Market	198	0.60	34
Materials	198	0.60	35
Management	196	0.59	36
Radiation	195	0.59	37
Photovoltaic	185	0.56	38
Flow	178	0.54	39
Efficiency	172	0.52	40
Oxide	171	0.52	41
Method	170	0.51	42
Data	158	0.48	43
Catalyst	156	0.47	44
Assessment	150	0.45	45
Diesel	150	0.45	46
Production	150	0.45	47
Turbine	150	0.45	48
Water	150	0.45	49
Temperature	149	0.45	50

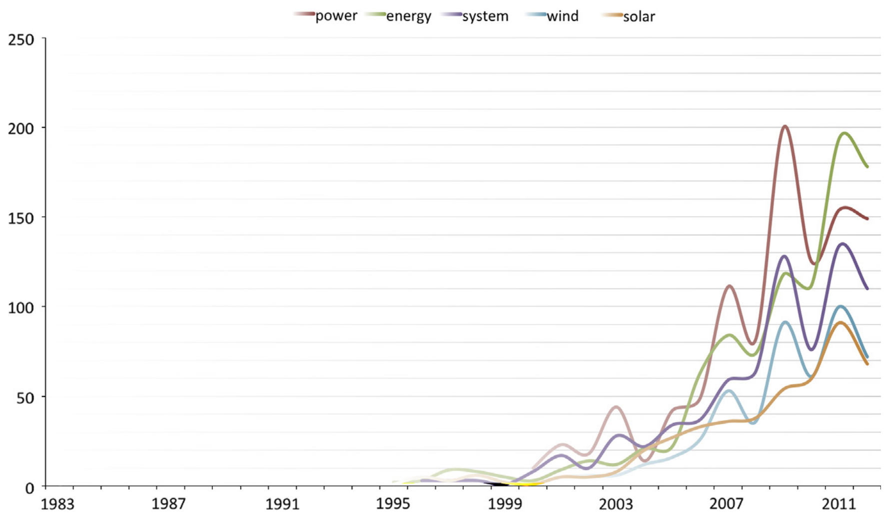

Fig. 10. Evolution of the 5 most used words in the authors keywords during the 1957–2012 period for the energy subject.

4. Discussion and conclusions

In this work a great deal of data pertaining to the Spanish institutions contribution to the scientific advance in the energy field during the 1957–2012 period has been brought to light. A grand total of 12,532 contributions in 20 different categories has been found. The increase in publications during this period has been exponential, specially in the Engineering, Materials Science and Chemistry categories. The work done has been mainly published in international journals (71%) and conference proceedings (26%), being English the predominant language (over 97%). Most part of the publications comes from the Comunidades of Madrid (31.55%), Catalonia (14.68%) and Andalusia (11.64%), adding the three of them more than half the national global. Worth mentioning the presence of Andalusia in the top 3 positions, given that traditionally is one of the Comunidades with less resources and less advanced in the country, probably due to the great number of universities in its territory. Besides, the 2 institutions with highest number of publications are autonomous public institutions, CSIC and CIEMAT. Just the two alone have more that 20% of the country scientific production. The rest of institutions are public universities like the Polytechnic University of Madrid, the Polytechnic University of Catalonia and the Polytechnic University of Valencia. Spain collaborates mainly with its biggest business partners, that is, USA and EU. France, USA, Germany and United Kingdom are the countries with a higher number of shared publications. Despite the close relationship at all levels that unites Spain and Latin America, no strong collaborating link is noticed, except with Mexico. The international collaboration evolution has stayed stable in recent years, at about the 40%. The keyword analysis of the studied publications reveals a great dispersion in their use. Many compound terms are used giving rise to a high number of unique terms (about 85% of the total). Furthermore, identical or very similar concepts are written differently creating a wider variety although clearly fictitious. The most used terms are power, energy, system, wind and solar. Besides these terms, others like hydrogen or renewable give an idea of the renewable energies strength in the current research scene, specially in recent years. The final conclusion is that this work shows that the Spanish contribution to energy topics produces a big amount of international publications in journals and outstanding conferences, also that Spain collaborates with a relevant number of international institutions, and that the energy research can be driven, in part, by the strong development of renewable energy in Spain.

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